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[54] **III-V NITRIDE COMPOUND SEMICONDUCTOR DEVICE AND METHOD FOR FABRICATING THE SAME**

[75] Inventors: **Daisuke Hanaoka**, Nara-ken; **Katsuki Furukawa**, Osaka, both of Japan

[73] Assignee: **Sharp Kabushiki Kaisha**, Osaka, Japan

[21] Appl. No.: **772,231**

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[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[6] **H01L 33/00**

[52] **U.S. Cl.** **257/123**; 257/94

[58] **Field of Search** 257/103, 94

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Primary Examiner—Stephen Meier
Attorney, Agent, or Firm—Morrison & Foerster LLP

[57] **ABSTRACT**

A III–V nitride compound semiconductor device of the present invention includes: at least one III–V nitride compound semiconductor layer; and an electrode layer made of non-single crystalline GaN in contact with the III–V nitride compound semiconductor layer.

4 Claims, 5 Drawing Sheets

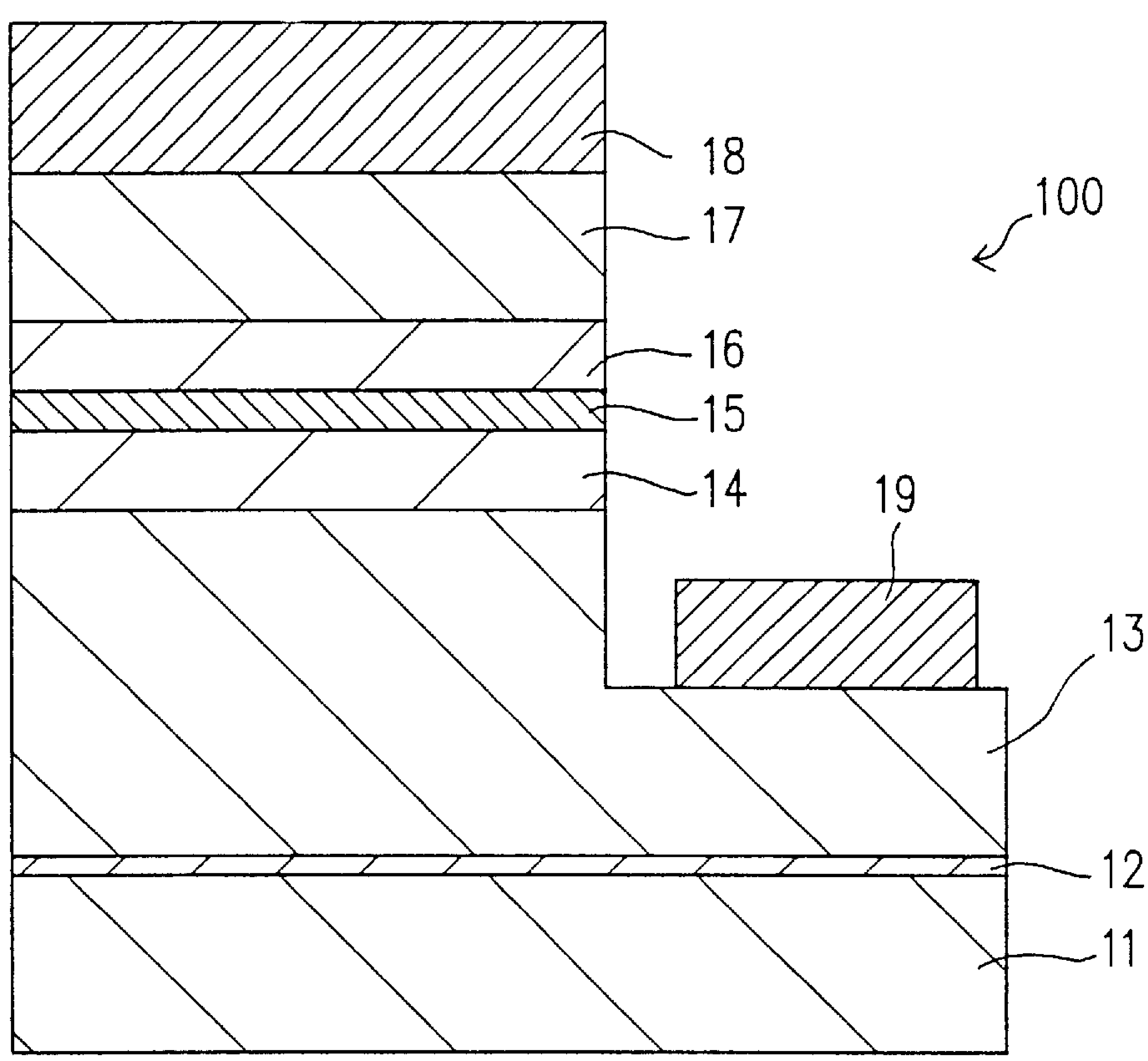


FIG. 1

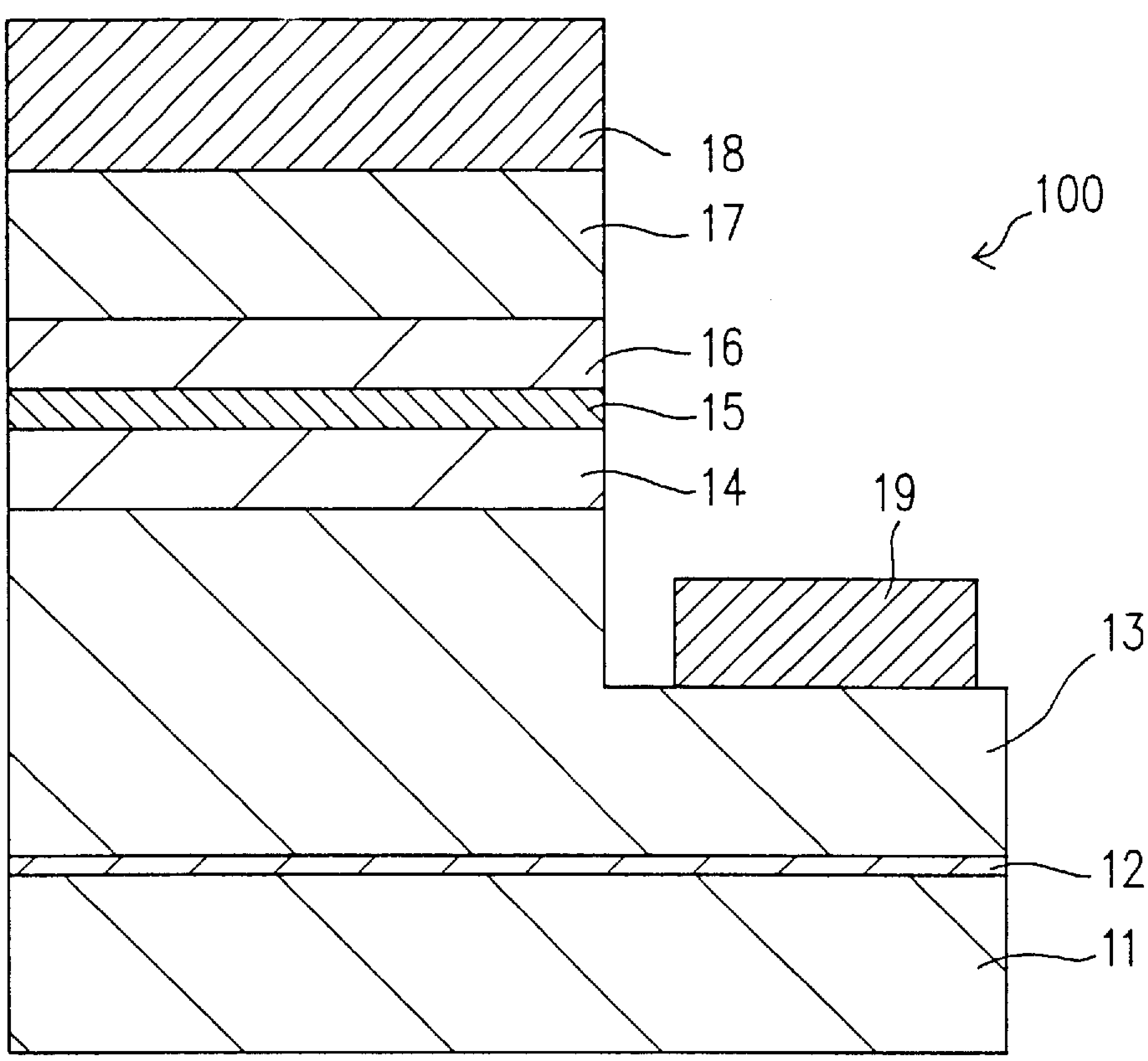


FIG. 2A

Formation of
p-type electrode layer

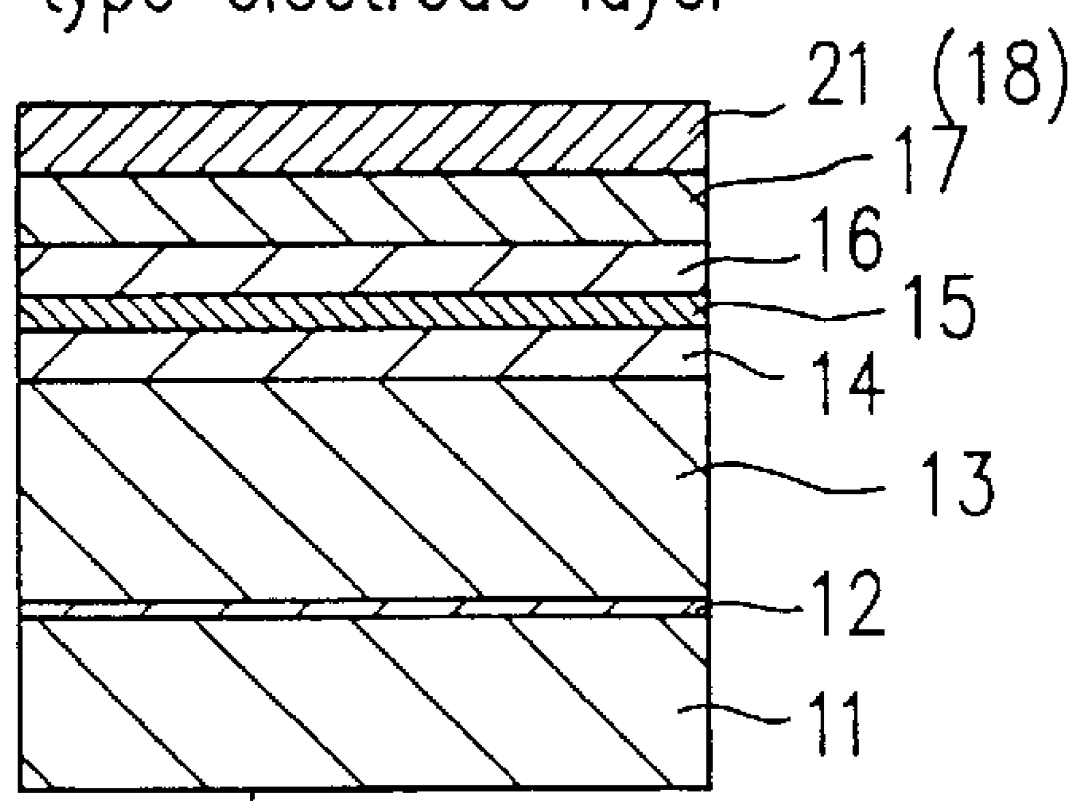


FIG. 2B

Formation of SiO2 mask

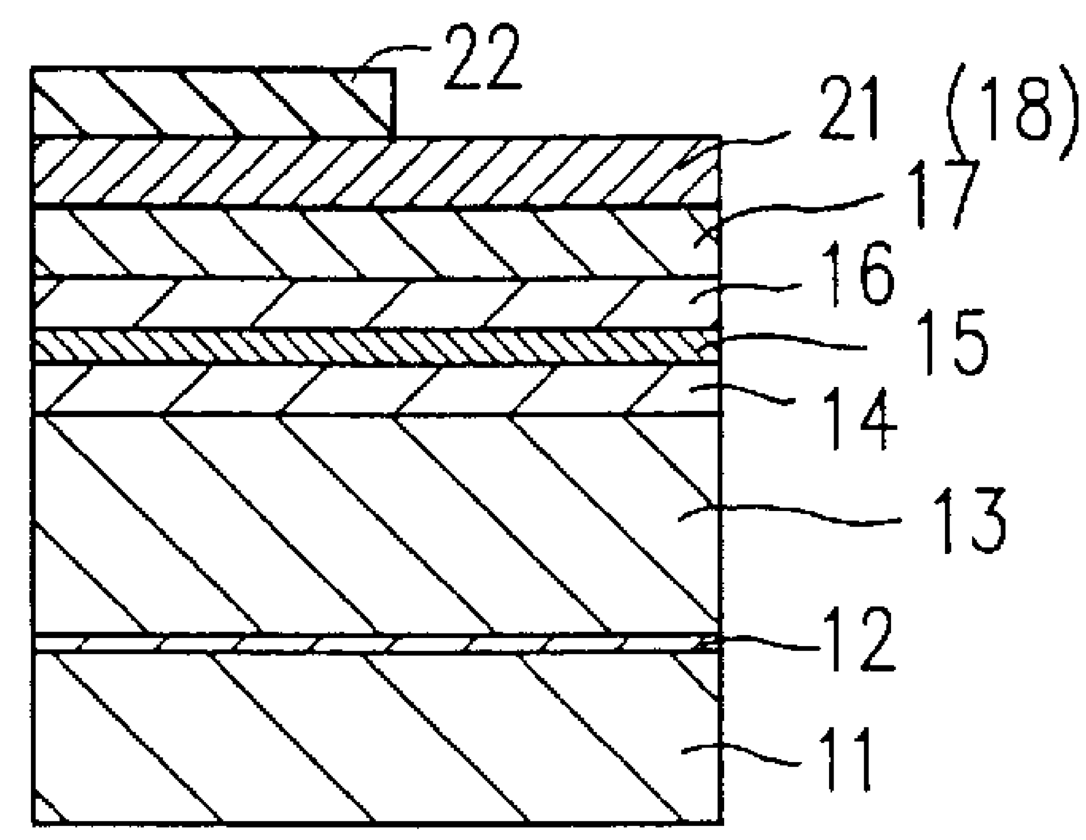


FIG. 2C

Etching

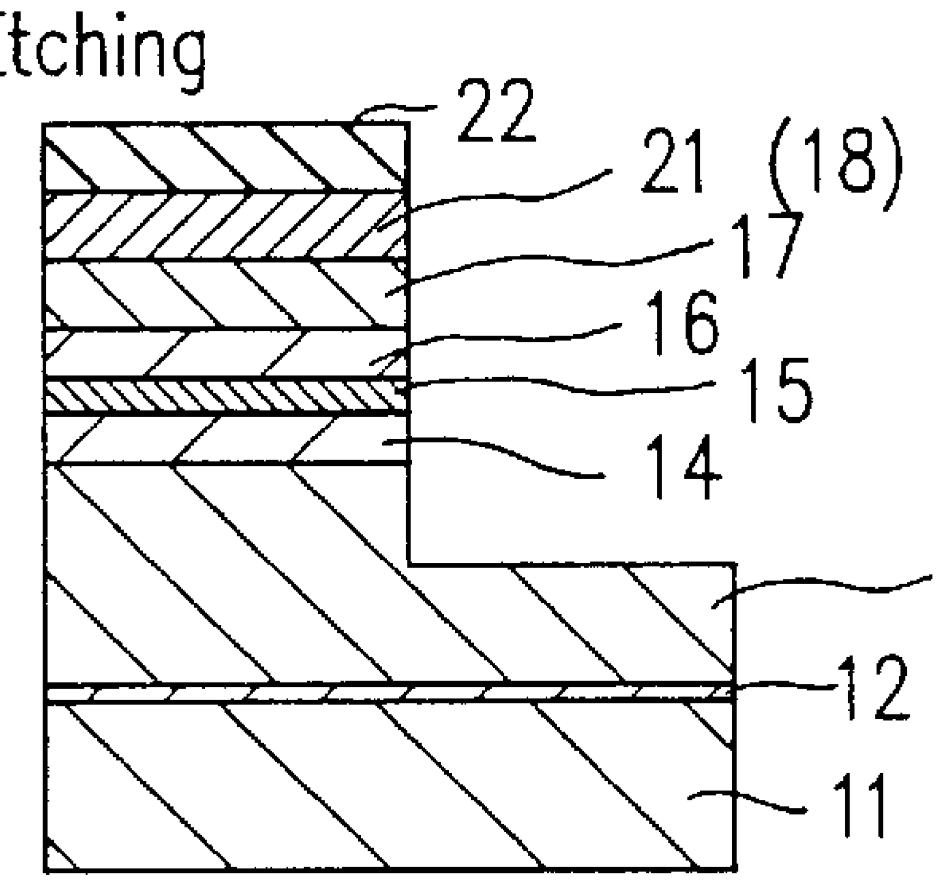


FIG. 2D

Removing of SiO2 mask

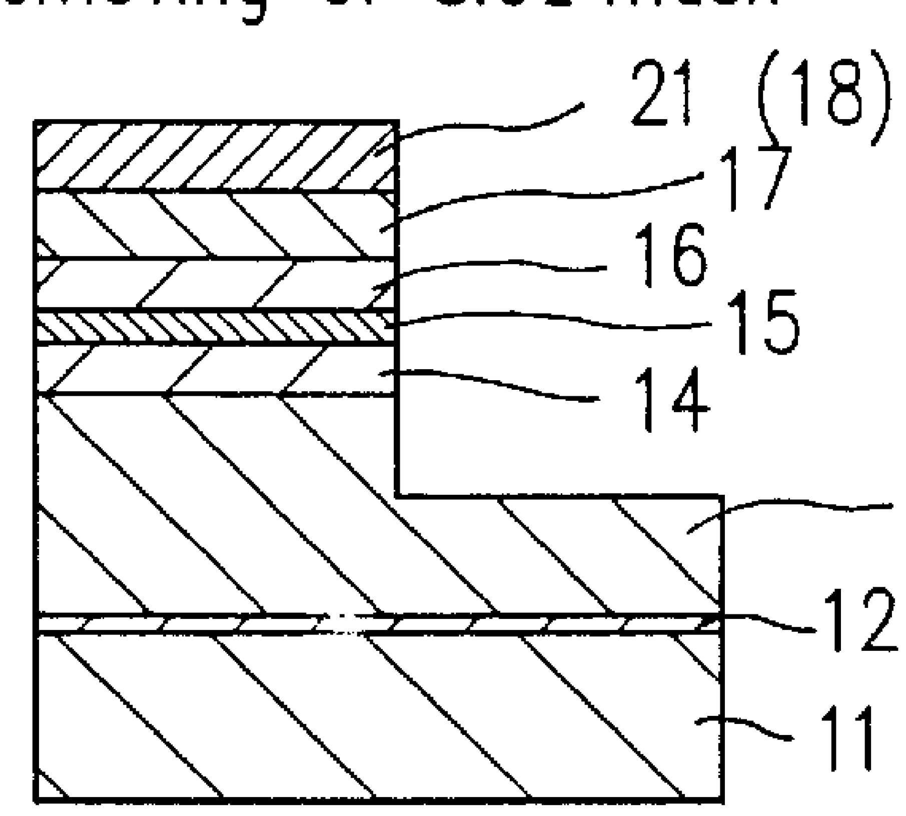


FIG. 2E

Formation of SiO2 mask

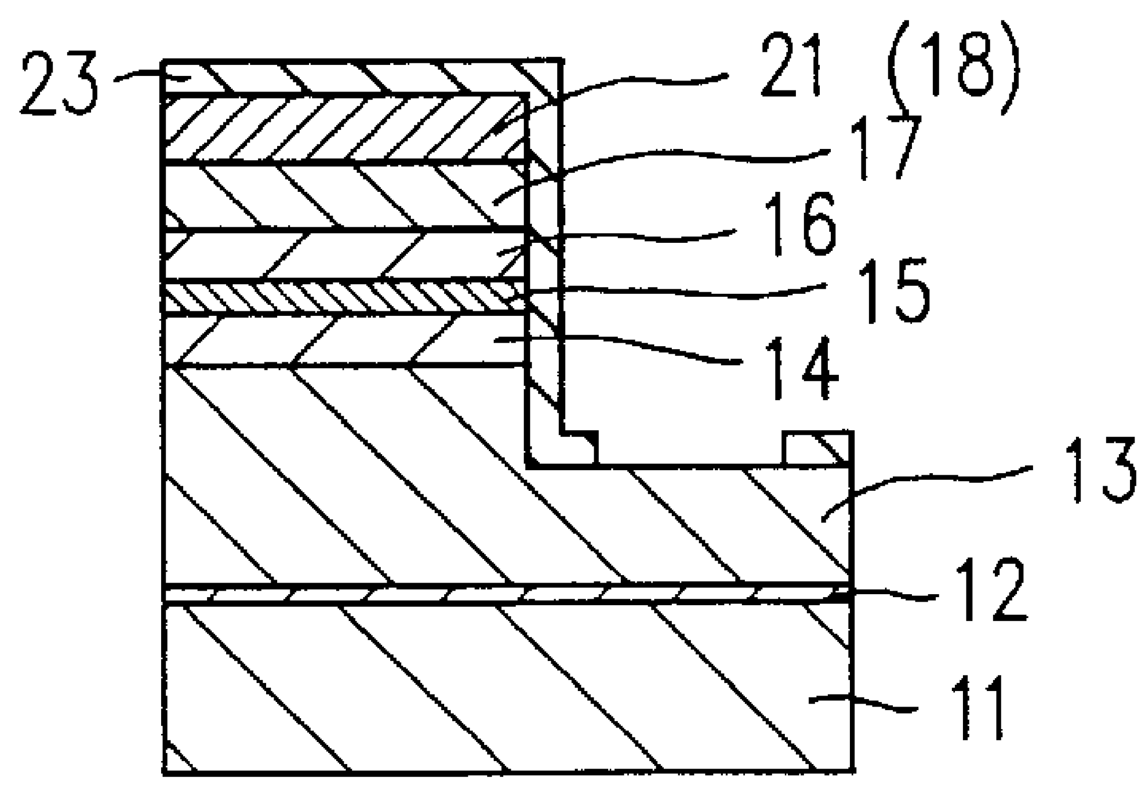


FIG. 2F

Formation of
n-type electrode layer

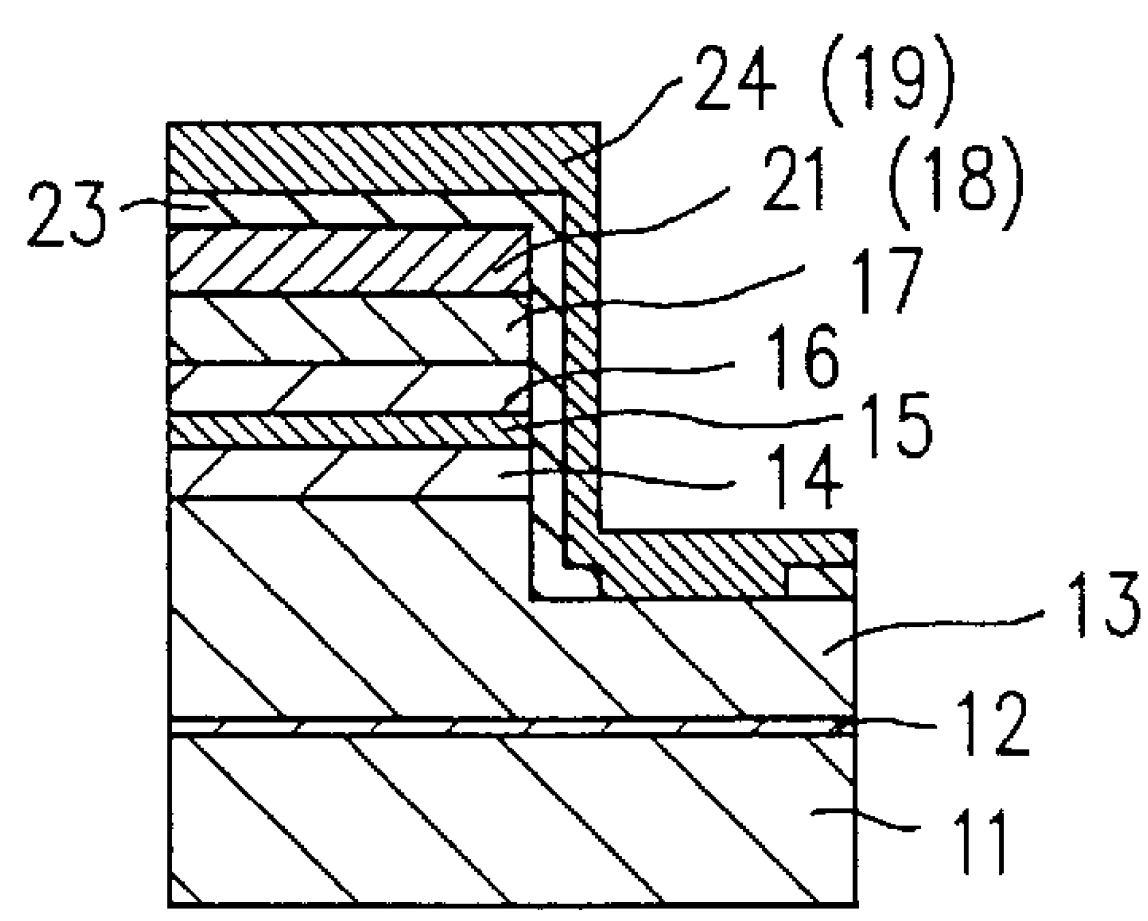


FIG. 2G

Removing of SiO2 mask

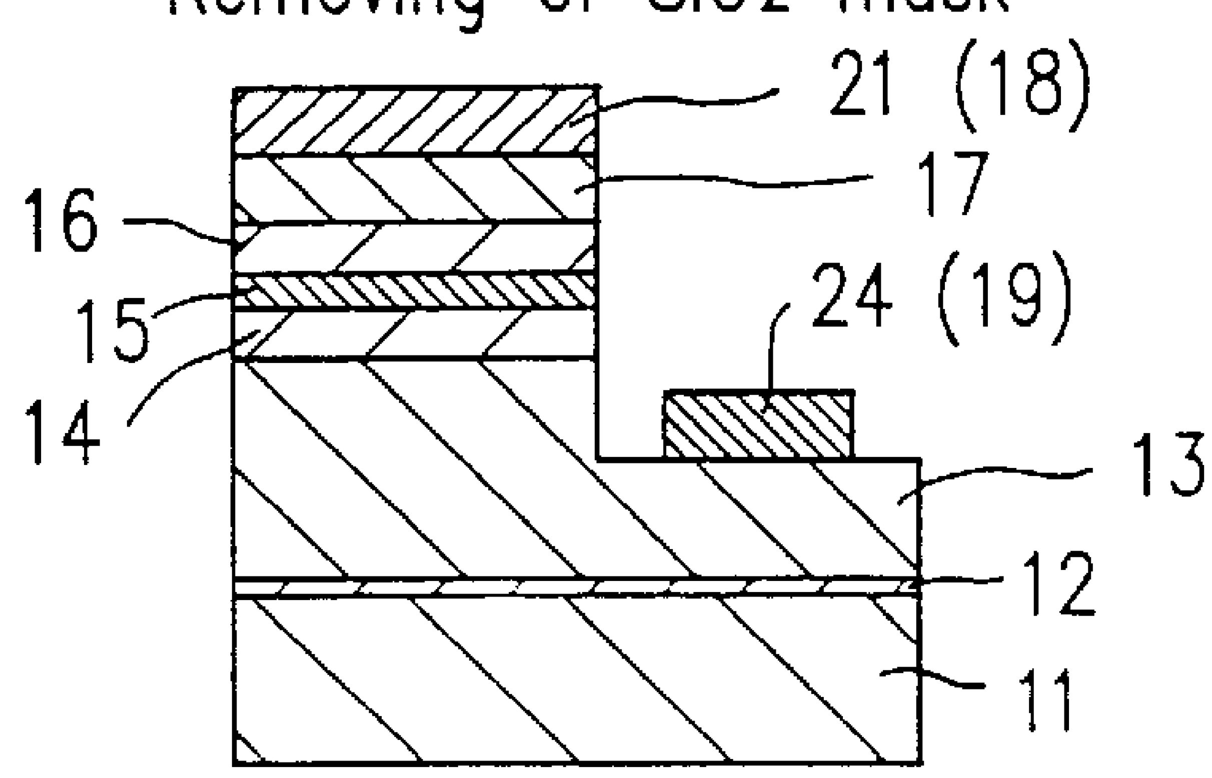
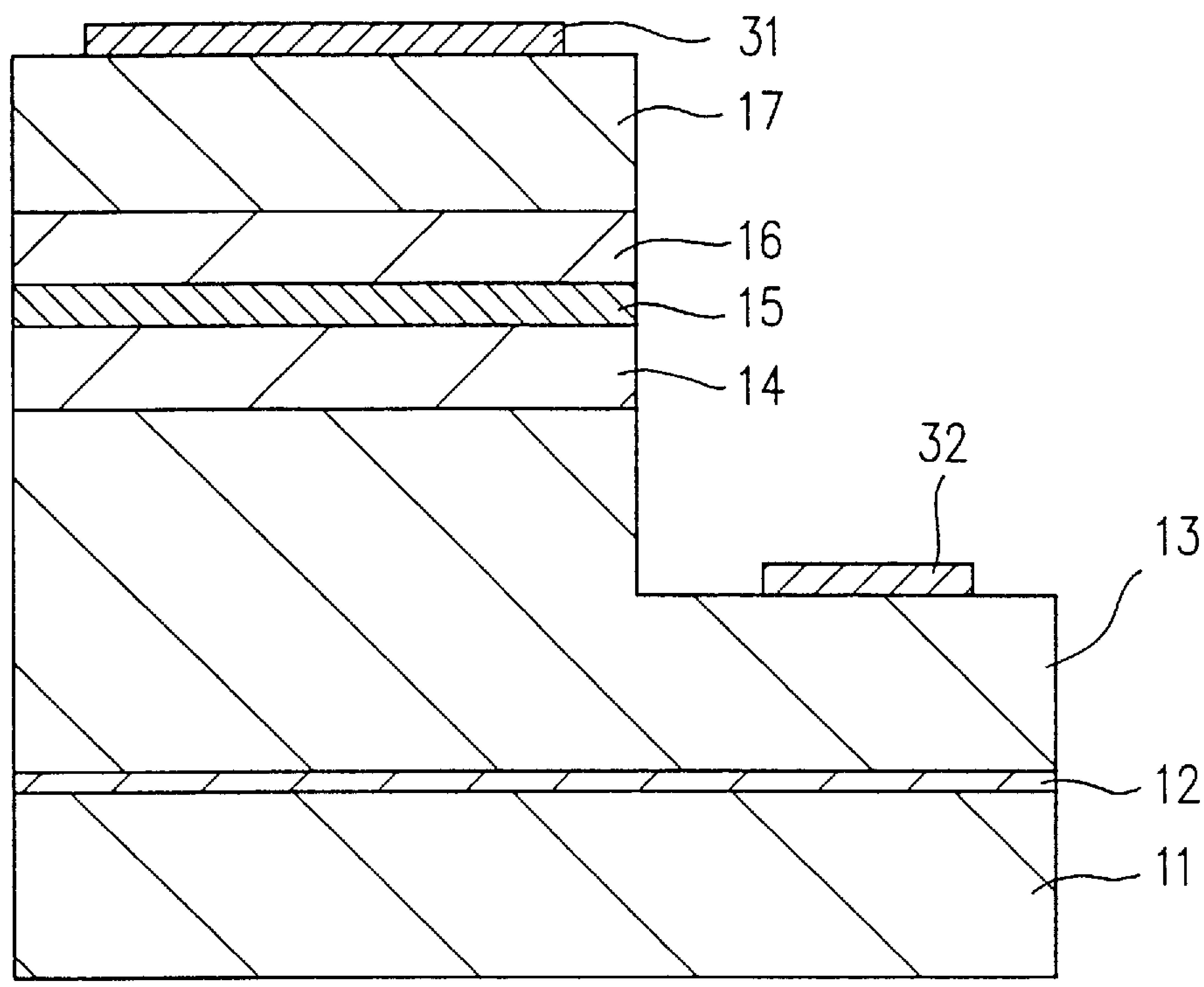


FIG. 3



PRIOR ART

FIG. 4

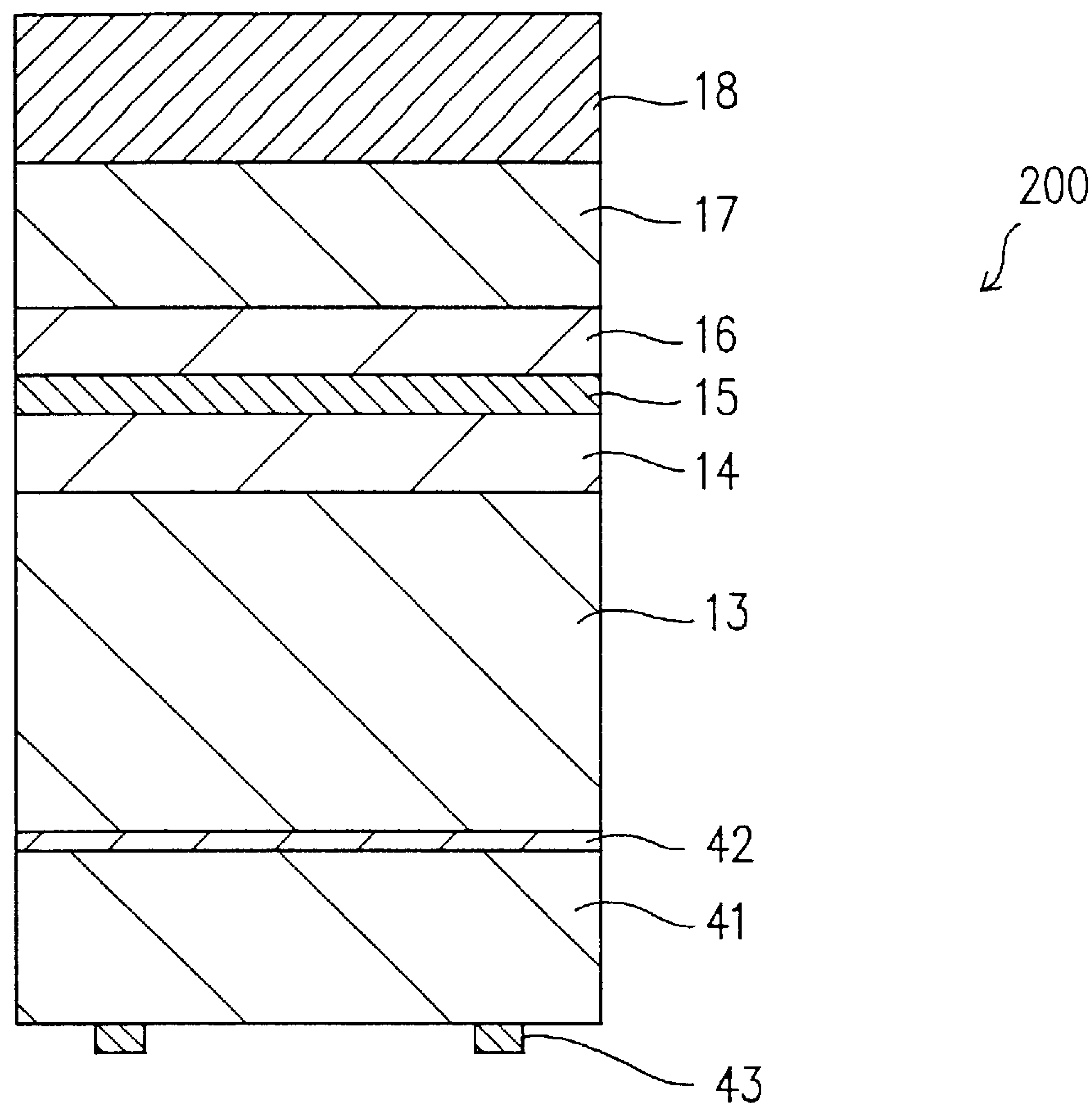
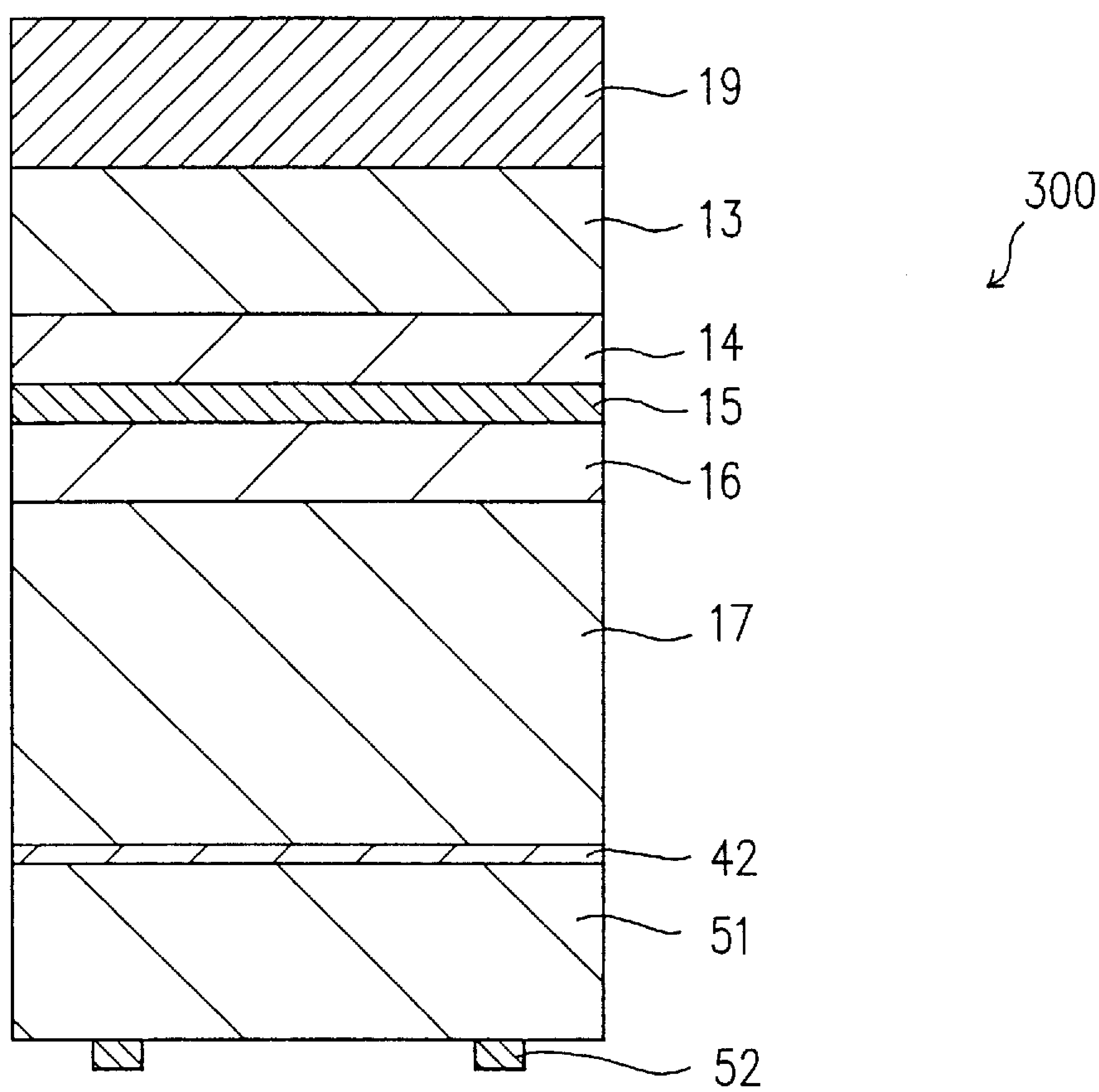


FIG. 5



III-V NITRIDE COMPOUND SEMICONDUCTOR DEVICE AND METHOD FOR FABRICATING THE SAME

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a III–V nitride compound semiconductor device, for example, a light-emitting device (such as a light-emitting diode and a laser diode) and a field-effect transistor.

2. Description of the Related Art

Active studies have been made on a semiconductor device formed by using a III–V nitride compound semiconductor. Although an n-type conductive layer can be easily formed by using the III–V nitride compound semiconductor, it was difficult to obtain a p-type conductive layer. Therefore, it was conventionally difficult to put a semiconductor device made of a III–V nitride compound semiconductor into practical use. However, since the p-type layer made of a III–V nitride compound semiconductor has recently been successfully obtained, a light-emitting device utilizing a pn junction has been fabricated.

An electrode utilizing various metal films has been examined as an electrode used in the semiconductor device. For example, in a semiconductor device requiring an Ohmic contact, Al is generally used for an n-type electrode. Materials such as Cr, Ti and In are also used for an n-type electrode. For a p-type electrode, Au is generally used. The use of Ni, Pt and Ag for a p-type electrode is now under examination.

However, in the case where the metal electrodes as described above are used, there arise disadvantages such as a poor adhesion to a III–V nitride compound semiconductor and a low physical strength. As a result, after the metal film is attached onto the III–V nitride compound semiconductor layer by evaporation or the like, problems such as peeling-off of the metal layer during a device fabrication process occur, thereby adversely lowering the reliability of a semiconductor device. For example, in a wire bonding process for connecting a metal wire to a metal electrode so as to output a current from a semiconductor device, peeling-off of the electrode occurs in approximately 3% to 15% of the total number of devices. As a result, such devices are rendered inoperative. This is a main cause for the reduction in fabrication yield.

SUMMARY OF THE INVENTION

A III–V nitride compound semiconductor device of the present invention includes: at least one III–V nitride compound semiconductor layer; and an electrode layer made of non-single crystalline GaN in contact with the III–V nitride compound semiconductor layer.

In one embodiment of the invention, the electrode layer has a hole concentration or an electron concentration of $5\times10^{19}cm^{-3}$ or higher.

In another embodiment of the invention, the III–V nitride compound semiconductor layer includes a layered structure including two or more layers each containing at least Ga as a Group III element and N as a Group V element.

In still another embodiment of the invention, the electrode layer has a transmittance of 80% or more with respect to a wavelength region of light emitted from the layered structure.

According to another aspect of the present invention, a method for fabricating a III–V nitride compound semiconductor device includes the steps of: forming a III–V nitride compound semiconductor layer; and forming an electrode layer made of non-single crystalline GaN on the III–V nitride compound semiconductor layer.

In one embodiment of the invention, the step of forming the electrode layer includes growing a GaN layer at a substrate temperature in the range of about 350° C. to 600° C. through metalorganic chemical vapor deposition.

In another embodiment of the invention, the step of forming the electrode layer includes growing a GaN layer at a substrate temperature in the range of about 150° C. to 450° C. through metalorganic chemical vapor deposition utilizing electron cyclotron resonance plasma.

Thus, the invention described herein makes possible the advantages of: (1) providing a III–V nitride compound semiconductor device including an electrode layer with an excellent adherence to a III–V nitride compound semiconductor layer and a high physical strength, capable of improving a yield; and (2) providing a method for fabricating the same.

These and other advantages of the present invention will become apparent to those skilled in the art upon reading and understanding the following detailed description with reference to the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cross-sectional view showing a layered structure of a III–V nitride compound semiconductor device in Example 1 according to the present invention.

FIGS. **2**A to **2**G are cross-sectional views, each showing a fabrication step of the III–V nitride compound semiconductor device shown in FIG. **1**.

FIG. **3** is a cross-sectional view showing a layered structure of a III–V nitride compound semiconductor device in a comparative example.

FIG. **4** is a cross-sectional view showing a layered structure of a III–V nitride compound semiconductor device in Example 2 according to the present invention.

FIG. **5** is a cross-sectional view showing a layered structure of a III–V nitride compound semiconductor device in Example 3 according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, the present invention will be described by way of illustrative examples.

The non-single crystalline GaN herein includes polycrystalline GaN, amorphous GaN and microcrystalline GaN excluding single crystalline GaN. In examples described below, the present invention will be described using polycrystalline GaN as an example of non-single crystalline GaN. However, the present invention is not limited to polycrystalline GaN. The same effect can be obtained with amorphous GaN and non-single crystalline GaN.

EXAMPLE 1

In Example 1, a light-emitting device is fabricated as a III–V nitride compound semiconductor device. In this light-emitting device, a polycrystalline GaN layer is used as an electrode layer formed so as to be in contact with a III–V nitride compound semiconductor layer.

FIG. **1** is a cross-sectional view showing a layered structure of a III–V nitride compound semiconductor device **100** in Example 1 of the present invention.

First, the structure of the III–V nitride compound semiconductor device **100** will be described with reference to FIG. **1**.

In FIG. **1**, a GaN buffer layer **12** having a thickness of 20 nm is provided on a C face of a sapphire is substrate **11**. On the GaN buffer layer **12**, an n-type GaN layer **13** having a thickness of 3000 nm (3 μm), an n-type $Al_{0.15}Ga_{0.85}N$ layer **14** having a thickness of 150 nm, an $In_{0.6}Ga_{0.94}N$:Zn layer **15** having a thickness of 50 nm, a p-type $Al_{0.15}Ga_{0.85}N$ layer **16** having a thickness of 150 nm and a p-type GaN layer **17** having a thickness of 300 nm are deposited in this order. A p-type GaN electrode layer **18** having a thickness of 300 nm, serving as an electrode for the p-type layer **17**, is provided on the layer **17**. Part of the thus obtained layered structure is removed from the top of the p-type GaN electrode layer **18** to the middle of the n-type GaN layer **13** by etching so as to partially expose the n-type GaN layer **13**. On the exposed part of the n-type GaN layer **13**, an n-type GaN electrode layer **19** having a thickness of 200 nm is provided as an electrode for the n-type layer **13**. In this manner, the light-emitting diode is constituted as the III–V nitride compound semiconductor device **100** of Example 1.

The light-emitting diode is fabricated as follows.

First, the GaN buffer layer **12** is grown to a thickness of 20 nm on the C face of the sapphire substrate **11** at a substrate temperature of 600° C. by using a metalorganic chemical vapor deposition (MOCVD) apparatus. On the GaN buffer layer **12**, the n-type GaN layer **13** with an electron concentration of 2×10^{18} cm^{-3}, which is doped with Si serving as an impurity, is grown to a thickness of 3000 nm (3 μm) at a substrate temperature of 1050° C. Subsequently, the n-type $Al_{0.15}Ga_{0.85}N$ layer **14** with an electron concentration of 2×10^{16} cm^{-3}, which is doped with Si serving as an impurity, is grown on the n-type GaN layer **13** to a thickness of 150 nm. Then, the $In_{0.06}Ga_{0.94}N$:Zn layer **15**, which is doped with Zn serving as an impurity, is grown to a thickness of 50 nm on the n-type $Al_{0.15}Ga_{0.85}N$ layer **14** at a substrate temperature of 800° C. The $In_{0.06}Ga_{0.94}N$:Zn layer **15** serves as an active light-emitting layer of the light-emitting diode. Zn, serving as a dopant, forms a deep acceptor level which functions as the luminescence center. The active light-emitting layer emits light having a wavelength of about 450 nm at room temperature. On the $In_{0.06}Ga_{0.94}N$:Zn layer **15**, the p-type $Al_{0.15}Ga_{0.85}N$ layer **16** with a hole concentration of 1×10^{18} cm^{-3}, which is doped with Mg serving as an impurity, is grown to a thickness of 150 nm at a substrate temperature of 1050° C. Subsequently, the p-type GaN layer **17** with a hole concentration of 1×10^{18} cm^{-3}, which is doped with Mg serving as an impurity, is grown to a thickness of 300 nm. In this manner, a layered structure having a doublehetero (DH) structure made of III–V nitride compound semiconductors is obtained.

Next, a p-type GaN layer serving as the electrode **18** for p-type layer (hereinafter, referred to simply as p-type electrode layer) is grown on the p-type GaN layer **17** by using a MOCVD apparatus. A growth process of the p-type GaN layer has a distinctive feature in that the layer is grown at a low substrate temperature. For example, in the case where a MOCVD method is employed, the GaN layer constituting the DH structure of the light-emitting diode is normally grown at a substrate temperature of about 1050° C. In the present invention, however, the GaN layer serving as an electrode layer is grown at a low substrate temperature, i.e., at between about 350° C. and 600° C. In Example 1, the Mg-doped p-type GaN layer having a hole concentration of 1×10^{20} cm^{-3} and a resistivity of 8×10^{-3} Ωcm is grown to a thickness of 300 nm at a substrate temperature of 500° C. The thus obtained p-type GaN layer has a crystallinity which is estimated through Reflection High Energy Electron Diffraction (RHEED). As a result, it is found that the p-type GaN layer has a polycrystalline structure. The p-type GaN itself exhibits a transmittance of 80% or higher with respect to light having a wavelength in the range of about 400 nm to 500 nm.

Thereafter, as described in detail below, the fabrication steps shown in FIGS. **2**A to **2**G are performed so as to form an n-type GaN layer serving as the electrode **19** for n-type layer (hereinafter, referred to as the n-type electrode layer **19**). In FIGS. **2**A to **2**G, the buffer layers **12** through the p-type GaN layer **17** are collectively referred to as a semiconductor layered structure **20**. The semiconductor layered structure **20** is a III–V nitride compound semiconductor layered structure having a DH structure including a pn junction.

First, as shown in FIG. **2**A, the semiconductor layered structure **20** and a p-type GaN layer **21** to be the p-type electrode layer **18** are successively formed on the substrate **11**, thereby fabricating a substrate part **101**. Then, as shown in FIG. **2**B, an SiO_2 layer **22** is formed on the p-type GaN layer **21** of the substrate part **101** so as to have a predetermined pattern. Next, as shown in FIG. **2**C, part of the semiconductor layered structure **20** and the p-type GaN layer **21** is removed by etching using the SiO_2 layer **22** as a mask so as to expose part of the n-type GaN layer **13** (which constitutes a portion of the layered structure **20**). Subsequently, the SiO_2 layer **22** is removed as shown in FIG. **2**D. Next, another SiO_2 layer **23**, serving as a mask for forming a n-type electrode layer, is formed so as to have a predetermined pattern as shown in FIG. **2**E. Thereafter, the thus obtained layered structure is introduced into an MOCVD apparatus so as to grow the n-type GaN layer **24** to be the n-type electrode layer **19** on the SiO_2 layer **23** as shown in FIG. **2**F. This growth process of the n-type GaN layer **24** has a distinct feature in that the n-type GaN layer **24** is grown at a low substrate temperature as in the case of the p-type GaN layer **21** serving as the p-type electrode layer **18**. For example, in the case where MOCVD method is employed, a growth process is conducted at a substrate temperature between about 350° C. and 600° C. In Example 1, the Si-doped n-type GaN layer **24** having an electron concentration of 2×10^{21} cm^{-3} and a resistivity of 2×10^{-4} Ωcm is grown to a thickness of 200 nm at a substrate temperature of 500° C. The thus obtained n-type GaN layer **24** has a crystallinity which is estimated through RHEED. As a result, it is found that the n-type GaN layer **24** has a polycrystalline structure. Moreover, the n-type GaN layer **24** itself exhibits a transmittance of 85% or more with respect to light having a wavelength in the range of 400 nm to 500 nm. Then, by removing the SiO_2 layer **23** as shown in FIG. **2**G, the p-type electrode layer **18** and the n-type electrode layer **19** are obtained.

The thus obtained wafer is cut into a chip by dicing, thereby completing the light-emitting diode **100** shown in FIG. **1** as the light-emitting device of Example 1.

The resultant chip is mounted onto a stem. The electrodes are led to the stem from the p-type electrode layer **18** and the n-type electrode layer **19** by wire bonding. Then, the characteristics thereof are estimated.

As a result, blue light emission with an operational voltage of 3.4 V at a current flow of 20 mA, a wavelength of 450 nm and a luminous intensity of 1000 mcd as typical characteristics is obtained. A defective device due to peeling-off of the electrode after mounting onto the stem or the like is scarcely found in the resultant devices. As a result, a yield of approximately 100% is obtained.

A comparative example will be described below for comparison with the Example 1 described above.

In this comparative example, a light-emitting diode is fabricated as a light-emitting device having metal electrodes **31** and **32** as shown in FIG. **3**. The same parts as those in Example 1 are denoted by the same reference numerals.

First, a layered structure having a DH structure made of III–V nitride compound semiconductors is fabricated on the C face of the sapphire substrate **11** as in Example 1 described above.

Subsequently, as in Example 1, an SiO_2 layer is formed on the p-type GaN layer **17** so as to have a predetermined pattern. Part of the thus obtained layered structure from the top of the p-type GaN layer **17** to the middle of the n-type GaN layer **13** is removed by etching using the patterned SiO_2 layer as a mask so as to partially expose the n-type GaN layer **13**. Thereafter, the SiO_2 layer is removed. Then, a photoresist serving as a mask for forming an n-type electrode layer is applied onto the surface of the n-type GaN layer **13** so as to have a predetermined pattern. After an Al layer serving as the metal electrode layer **32** for n-type layer (hereinafter, referred to as the n-type metal electrode layer **32**) is formed by evaporation, the photoresist is removed. In a similar manner, a photoresist serving as a mask for forming a p-type electrode layer is applied onto the surface of the p-type GaN layer **17** so as to have a predetermined pattern. After the Au layer serving as the p-type metal electrode layer **31** is formed by evaporation, the photoresist is removed. By the above process, the p-type metal electrode layer **31** and the n-type metal electrode layer **32** are obtained.

The thus obtained wafer is cut into a chip by dicing, thereby completing a light-emitting diode as shown in FIG. **3**.

The resultant chip is mounted onto a stem. The electrodes are led to the stem from the p-type metal electrode layer **31** and the n-type metal electrode layer **32** by wire bonding. Then, the characteristics thereof are estimated.

As a result, blue light emission with an operational voltage of 3.8 V at a current flow of 20 mA, a wavelength of 450 nm and a luminous intensity of 500 mcd as typical characteristics is obtained. About 10% of the total devices are defective devices which are rendered inoperative due to peeling-off of the electrodes after mounting onto the stem or the like.

Therefore, the experimental results of Example 1 and the comparative example show the following. In the light-emitting diode of Example 1 using polycrystalline GaN electrode layers as the p-type electrode layer **18** layer and the n-type electrode layer **19**, the yield and the reliability of the semiconductor device can be remarkably improved as compared with the light-emitting diode of the comparative example using the metal layers, i.e., Au layer and Al layer, as the electrodes. It is considered that a yield and reliability are improved because the polycrystalline GaN electrode layer has a good adherence to the III–V nitride compound semiconductor layer and a high physical strength as compared with the metal electrode. Moreover, in Example 1 using the polycrystalline GaN electrode layer, an operational voltage can be lowered as compared with the comparative example using the metal electrode. It is considered that a low operational voltage is obtained owing to a good Ohmic contact of the polycrystalline GaN electrode layer with the III–V nitride compound semiconductor layer as compared with the metal electrode.

Furthermore, in Example 1 using the polycrystalline GaN electrode layer, a high luminous intensity is obtained as compared with the comparative example using the metal electrode. The reason for this is considered as follows. In the case where the polycrystalline GaN electrode layer is used, since light emitted from the light-emitting layer immediately below the upper electrode passes through the polycrystalline GaN electrode, light is externally output from the upper part. On the other hand, since light is reflected by the metal electrode in the case where the metal electrodes are used, a light output efficiency from the upper part is low. Furthermore, since the polycrystalline GaN electrode can be fabricated by the same film growth apparatus as that used for forming the III–V nitride compound semiconductor layer constituting the device structure, the fabrication process can be advantageously simplified.

EXAMPLE 2

In Example 2, a light-emitting device having a structure different from that of the light-emitting device of Example 1 is fabricated as a III–V nitride compound semiconductor device. In the light-emitting device of Example 2, the polycrystalline GaN layer is used as an electrode layer formed so as to be in contact with the III–V nitride compound semiconductor layer.

FIG. **4** is a cross-sectional view showing a layered structure of a III–V nitride compound semiconductor device **200** in Example 2 of the present invention. The same parts as those in FIG. **1** are denoted by the same reference numerals.

In FIG. **4**, an AlN buffer layer **42** having a thickness of 30 nm is provided on an n-type 6H-SiC substrate **41** with a (0001) Si face. On the AlN buffer layer **42**, the n-type GaN layer **13**, the n-type $Al_{0.15}Ga_{0.85}N$ layer **14**, the $In_{0.06}Ga_{0.94}N$:Zn layer **15**, the p-type $Al_{0.15}Ga_{0.85}N$ layer **16**, and the p-type GaN layer **17** are deposited in this order as in Example 1. On the p-type GaN layer **17**, a p-type GaN electrode layer serving as the p-type electrode layer **18** is provided. On part of the bottom face of the n-type 6H-SiC substrate **41**, a Ni electrode layer **43** serving as an electrode for the n-type layer (hereinafter, referred to as the n-type electrode layer **43**) is provided. The light-emitting diode as the Ill–V nitride compound semiconductor device of Example 2 has the structure as described above.

The light-emitting diode having the above structure is fabricated as follows.

The n-type 6H-SiC substrate **41** is introduced into an MOCVD apparatus. The AiN buffer layer **42** is grown to a thickness of 30 nm at a substrate temperature of 1050° C. On the AlN buffer layer **42**, the n-type GaN layer **13**, the n-type $Al_{0.15}Ga_{0.85}N$ layer **14**, the $In_{0.06}Ga_{0.94}N$:Zn layer **15**, the p-type $Al_{0.15}Ga_{0.85}N$ layer **16**, and the p-type GaN layer **17** are successively grown in the same manner as in Example 1. In this manner, a layered structure having a DH structure made of III–V nitride compound semiconductors is fabricated.

Next, the p-type GaN layer serving as the p-type electrode layer **18** is grown on the p-type GaN layer **17** by using a molecular beam epitaxy (MBE) apparatus. The MBE apparatus uses a nitrogen source material obtained by exciting an N_2 gas through a radio frequency plasma. A growth process of the p-type GaN layer has a distinct feature in that the layer is grown at a low substrate temperature as in Example 1. For example, in the case where an MBE method is employed, the GaN layer constituting the DH structure of the light-emitting diode is normally grown at a substrate temperature between 600° C. and 800° C. in order to obtain a high quality GaN layer. In Example 2 of the present invention, the GaN layer serving as the electrode layer is grown at a low substrate temperature, i.e., between about 150° C. and 400° C. As a result of the growth process at a low temperature, single crystallinity is lowered, thereby obtaining a polycrystalline structure. In Example 2, the Mg-doped p-type GaN layer having a hole concentration of 3×10^{-20} $\Omega cm^{31\ 3}$ and a resistivity of 5×10^{-3} Ωcm is grown to a thickness of 300 nm at a substrate temperature of 350° C. The thus obtained p-type GaN layer has a crystallinity which is estimated through RHEED. As a result, it is found that the p-type GaN layer has a polycrystalline structure. The p-type GaN layer **18** itself exhibits a transmittance of 80% or more with respect to light having a wavelength in the range of about 400 nm to 500 nm.

Thereafter, on part of the bottom face of the n-type 6H-SiC substrate **41**, the Ni electrode layer **43** is formed as an n-type electrode layer by evaporation.

The resultant wafer is cut into a chip by dicing, thereby obtaining a light-emitting diode as shown in FIG. **4**.

The chip is mounted onto a stem. The electrodes are led to the stem from the n-type electrode layer **43** directly and from the p-type electrode layer **18** by wire bonding. The characteristics of the light-emitting diode are estimated.

As a result, blue light emission with an operational voltage of 3.3 V at a current flow of 20 mA, a wavelength of 450 nm and a luminous intensity of 900 mcd as typical characteristics is obtained. A defective device due to peeling-off of the electrode after mounting on the stems or the like is scarcely found. As a result, a yield of approximately 100% is obtained.

EXAMPLE 3

In Example 3, a light-emitting device having a reverse layered structure to that of the light-emitting device of Example 2 is fabricated as a III–V nitride compound semiconductor device. A polycrystalline GaN layer is used as an electrode layer formed so as to be in contact with the III–V nitride compound semiconductor layer.

FIG. **5** is a cross-sectional view showing a layered structure of a III–V nitride compound semiconductor device **300** in Example 3 of the present invention.

In FIG. **5**, the same AlN buffer layer **42** as that of Example 2 is provided on a p-type 6H-SiC substrate **51** with a (0001) Si face. On the AlN buffer layer **42**, the same III–V nitride compound semiconductor layers as those in Example 2 are successively deposited in a reverse order, that is, in the order of the p-type GaN layer **17**, the p-type $Al_{0.15}Ga_{0.85}N$ layer **16**, the $In_{0.06}Ga_{0.94}N$:Zn layer **15**, the n-type $Al_{0.15}Ga_{0.85}N$ layer **14** and the n-type GaN layer **13**. On the n-type GaN layer **13**, an n-type GaN electrode layer having a thickness of 300 nm is provided as the n-type electrode layer **19**. On part of the bottom of the p-type 6H-SiC substrate **51**, a Ti/Al electrode layer **52** is provided as an electrode layer for the p-type layer (hereinafter, referred to as the p-type electrode layer **52**). The light-emitting diode **300** as a III–V nitride compound semiconductor device of Example 3 has the structure as described above.

The light-emitting diode **300** is fabricated as follows.

First, the p-type 6H-SiC substrate **51** is introduced into an MOCVD apparatus so as to grow the AlN buffer layer **42** in the same manner as in Example 2. Then, the p-type GaN layer **17**, the p-type $Al_{0.15}Ga_{0.85}N$ layer **16**, the $In_{0.06}Ga_{0.94}N$:Zn layer **15**, the n-type $Al_{0.15}Ga_{0.85}N$ layer **14** and the n-type GaN layer **13** are successively grown on the AlN buffer layer **42**, that is, in the reverse order of Example 2, thereby fabricating a layered structure having a DH structure made of III–V nitride compound semiconductors.

Next, an n-type GaN layer to be the n-type electrode layer **19** is grown on the n-type GaN layer **13** by using an electron cyclotron resonance (ECR)-MOCVD apparatus. The ECR-MOCVD apparatus uses active nitrogen obtained by performing an ECR microwave plasma excitation for an N_2 gas as a nitrogen source material. A growth process of the n-type GaN layer has a distinct feature in that the layer is grown at a low substrate temperature as in Example 1 described above. For example, in the case where the ECR-MOCVD method is employed, a GaN layer serving as an electrode layer is grown at a low substrate temperature, i.e., between 150° C. and 450° C. In Example 3, an n-type GaN layer having an electron concentration of 1×10^{21} cm^{-3} and a resistivity of 4×10^{-4} Ωcm, which is doped with oxygen as an impurity, is grown to a thickness of 300 nm at a substrate temperature of 370° C. The thus obtained n-type GaN layer has a crystallinity which is estimated through RHEED. As a result, it is found that the n-type GaN layer has a polycrystalline structure. The n-type GaN itself exhibits a transmittance of 80% or higher with respect to light having a wavelength in the range of about 400 nm to 500 nm.

Thereafter, on a part of the bottom face of the p-type 6H-SiC substrate **51**, the Ti/Al electrode layer **52** is formed as an electrode layer for the p-type layer by evaporation.

The thus obtained wafer is out into a chip by dicing, thereby completing the light-emitting diode as shown in FIG. **5**.

The chip is mounted onto a stem. The electrodes are led to the stem from the p-type electrode layer **52** directly and from the n-type electrode layer **19** by wire bonding, and the characteristics of the light-emitting diode are estimated. In Example 3, Al is deposited as a pad on a region where wire bonding is performed so as to lessen the impact of wire bonding. In this case, Al does not affect the characteristics of the electrode.

As a result, blue light emission with an operational voltage of 3.4 V at a current flow of 20 mA, a light-emitting wavelength of 450 nm and a luminous intensity of 800 mcd as typical characteristics is obtained. A defective device due to peeling-off of the electrode after mounting on the stems or the like is scarcely found. As a result, a yield of approximately 100% is obtained.

Thus, in the III–V nitride compound semiconductor devices of Examples 1 to 3 according to the present invention, a polycrystalline GaN layer is used as an electrode layer formed so as to be in contact with the III–V nitride compound semiconductor layer.

As described above, in the case where the non-single crystalline GaN electrode layer is used, a good adherence to the III–V nitride compound semiconductor layer and a high physical strength are obtained as compared with the conventional case where a metal electrode layer is used. Therefore, a fabrication yield of the semiconductor device is improved as well as the reliability of the semiconductor device. Moreover, since the non-single crystalline GaN electrode layer has a high transparency, a transmittance with respect to light emitted from the layered structure can be increased. Light, which is not conventionally externally output due to reflection by a metal electrode, is externally available. A transmittance with respect to light emitted from the layered structure is preferably at least 70% or more, and more preferably 80%. In such a case, a transmittance can be increased to 80% or more with respect to emitted light having a wavelength in the range of about 400 nm to 500 nm by adjusting a thickness of the electrode layer or selecting an impurity contained in the electrode layer. As a result, such a light-emitting device is rendered applicable as a blue-light emitting device.

The reason that the non-single crystalline GaN layer is employed in the present invention is as follows. Owing to the recent progress in crystal growth techniques, a GaN layer with excellent crystallinity can be obtained. Moreover, improvement in a doping technique enables a conductivity control of the n-type and p-type layers. However, since a single crystalline GaN layer has a relatively high resistivity, a current is not sufficiently diffused in the semiconductor layer in the case where the single crystalline GaN layer is used as an electrode layer. In order to lower the resistivity of the electrode layer, it may be possible to dope the single crystalline GaN layer with an impurity. Up to now, however, a GaN layer with a high carrier concentration still maintaining single-crystallinity has not been successfully obtained. For example, an n-type single crystalline GaN layer having an electron concentration of about 1×10^{19} cm^{-3} and a p-type single crystalline GaN layer having a hole concentration of about 1×10^{18} cm^{-3} are only currently available. In order to sufficiently diffuse a current in the semiconductor layer, it is preferred that a resistivity of the electrode layer is 1×10^{-2} Ωcm or lower. Therefore, if the light-emitting device is fabricated using the single crystalline GaN layer, a light-emitting region is limited. As a result, light with a high intensity cannot be obtained.

On the other hand, a non-single crystalline GaN layer has a low resistivity. Moreover, it is possible to increase a hole concentration or an electron concentration to $5\times10^{19}cm^{-3}$ or higher in the non-single crystalline GaN layer. A resistivity of the non-single crystalline GaN layer can be lowered to 1×10^{-2} Ωcm or even lower. Up to now, a film having a resistivity of 1×10^{-5} Ωcm has been obtained. With the GaN layer having such a low resistivity, it is possible to ensure sufficient diffusion of a current so that the GaN layer can function as an electrode layer. Thus, by using the non-single crystalline GaN electrode layer for a light-emitting device, a light-emitting region can be increased, thereby obtaining light with a high intensity. Furthermore, since the non-single crystalline GaN layer has an excellent Ohmic contact with the III–V nitride compound semiconductor layer constituting the device structure as compared with a conventional metal electrode, it is possible to lower an operational voltage.

In order to grow the non-single crystalline GaN electrode layer, a growth method commonly used to grow III–V nitride compound semiconductor layers can be used. Such a method includes, for example, an evaporation, sputtering, chemical vapor deposition, metalorganic chemical vapor deposition (MOCVD), MOCVD employing electron cyclotron resonance (ECR) plasma and molecular beam epitaxy (MBE). Therefore, since the electrode layer can be grown by using the same film growth apparatus as that used for the semiconductor layers constituting the device structure, the fabrication process can be simplified as compared with a conventional method using two different growth apparatuses, one for the device structure and the other for the electrode layer. When the non-single crystalline GaN layer is grown, the layer is grown at a lower temperature than that for the III–V nitride compound semiconductor layer. For example, the electrode layer is grown at a lower substrate temperature between about 350° C. and 600° C. in the case where a MOCVD method is employed, and at a lower substrate temperature between about 150° C. and 450° C. in the case where a MOCVD method utilizing ECR plasma is employed. As a result, a non-single crystalline GaN layer as the electrode layer is obtained.

Furthermore, it is possible to increase a carrier concentration by doping the non-single crystalline GaN layer with an impurity. For example, in the case where an n-type GaN layer is intended to be obtained, a Group IV element such as silicon, germanium, tin and titanium, or a Group VI element such as oxygen, sulfur and selenium, may be used. In the case where a p-type GaN layer is intended to be obtained, a Group II element such as magnesium and beryllium may be used.

The III–V nitride compound semiconductor layer may be used as one or more layers constituting a device structure, for example, a light-emitting device such as a light-emitting diode and a laser diode and an electronic device such as a field effect transistor. In the case where the III–V nitride compound semiconductor layer is used for the light-emitting device, a light-emitting region is constituted by utilizing a pn junction such as that of a doublehetero (DH) structure. A blue-light-emitting device having a wavelength in the range of about 400 nm to 500 nm can be fabricated by using a material containing at least Ga as a Group III element and N as a Group V element, for example, AlGaN, InGaN and AlGaInN. A composition ratio of a mixed crystal material of the semiconductor layer can be appropriately varied.

Although the polycrystalline GaN electrode layer is formed so as to be in contact with the III–V nitride compound semiconductor layer in Examples 1 to 3 described above, a non-single crystalline GaN electrode layer may be formed instead. In this case, the single crystalline structure is disrupted to obtain a non-single crystalline GaN. As a result, a high carrier concentration or a low resistivity can be obtained.

As described above, according to the present invention, since a non-single crystalline GaN electrode layer is formed as an electrode in contact with a III–V nitride compound semiconductor layer, an adherence to the semiconductor layer and a physical strength thereof can be improved. Therefore, problems such as peeling-off of the electrode, which conventionally occur, do not occur during a fabrication process. As a result, the fabrication yield and the reliability of a semiconductor device can be improved.

Moreover, since the non-single crystalline GaN electrode layer has a good Ohmic contact with the III–V nitride compound semiconductor layer, an operational voltage of the semiconductor device can be lowered.

Since GaN constituting such an electrode layer is not single crystalline, it is possible to increase a carrier concentration while attaining a low electrical resistivity. Therefore, it is possible to ensure sufficient diffusion of a current so that the layer serves as an electrode. For example, a hole concentration or an electron concentration of $5\times10^{19}cm^{-3}$ or more can be obtained with non-single crystalline GaN.

Two or more layers containing at least Ga as a Group III element and N as a Group V element may be deposited as the III–V nitride compound semiconductor layers, thereby constituting a blue-light-emitting device. In this case, a transmittance with respect to light emitted from a layered structure, having a wavelength in the range of, for example, about 400 nm to 500 nm, can be increased to 80% or more.

Furthermore, in the case where an electrode layer made of GaN is grown, it is possible to easily grow the GaN electrode layer at a temperature lower than that for the growth of the III–V nitride compound semiconductor layer by using an apparatus commonly used for growing a III–V nitride compound semiconductor layer, such as a metalorganic chemical vapor deposition (MOCVD) apparatus. For example, the electrode layer is formed at a lower substrate temperature between about 350° C. and 600° C. in the case where a MOCVD method is employed, and at a substrate temperature between about 150° C. and 450° C. in the case where a MOCVD method utilizing an ECR plasma is employed. As a result, a non-single crystalline GaN layer as the electrode layer can be obtained.

Furthermore, since a non-single crystalline GaN electrode layer has a high transmittance with respect to light emitted from a layered structure, it is possible to improve the light output efficiency.

In addition, since the non-single crystalline GaN electrode layer can be fabricated by the same growth apparatus as that used for the III–V nitride compound semiconductor layers constituting the device structure, it is possible to successively form the III–V nitride compound semiconductor layers and the non-single crystalline GaN electrode layer. Consequently, the fabrication process can be simplified.

Various other modifications will be apparent to and can be readily made by those skilled in the art without departing from the scope and spirit of this invention. Accordingly, it is not intended that the scope of the claims appended hereto be limited to the description as set forth herein, but rather that the claims be broadly construed.

What is claimed is:

1. A III–V nitride compound semiconductor device comprising:

at least one III–V nitride compound semiconductor layer; and

an electrode layer made of non-single crystalline GaN in contact with the III–V nitride compound semiconductor-layer.

2. A III–V nitride compound semiconductor device according to claim **1**, wherein the electrode layer comprises a hole concentration or an electron concentration of 5×10^{19}cm−3 or higher.

3. A III–V nitride compound semiconductor device according to claim **1**, wherein the III–V nitride compound semiconductor layer comprises a layered structure including two or more layers each containing at least Ga as a Group III element and N as a Group V element.

4. A III–V nitride compound semiconductor device according to claim **3**, wherein the electrode layer has a transmittance of 80% or more with respect to a wavelength region of light emitted from the layered structure.

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